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A SURVEY OF EXISTING COMPUTER PROGRAMS FOR AIRCREW WORKLOAD ASS--ETC(U)

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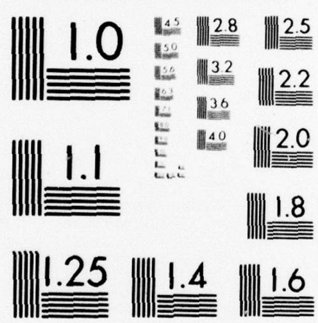
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Alan M. Poston

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Due to increased concerns of crew workload in tactical nap-of-the-earth environments, increased importance has been placed on the need to utilize a computer simulation to serve as a predictor, or estimator, of crew loading. The US Army Human Engineering Laboratory conducted a survey of existing computer programs which can be used for workload assessment. Each program was assessed in terms of input requirements, processing procedures, outputs available, as well as any other pertinent information. Conclusions are drawn and recommendations are made as to how the Army should approach the problem of obtaining a suitable computer program.

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May 1978

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A SURVEY OF EXISTING COMPUTER PROGRAMS FOR AIRCREW WORKLOAD ASSESSMENT

INTRODUCTION

The concept of workload has never been exactly defined, but it generally refers to the total task performance demand placed on an operator of a given system. Included in this concept is the aircrew's ability to process all relevant information, make all necessary judgments and decisions, take all necessary actions at any point in a mission, and still have reserve capacity for handling unexpected or emergency events. When the aviators are operating at nap-of-the-earth altitudes in a high threat environment, the workload can approach or exceed the limits of human capacity. There exists a need to gain a better understanding of the effects of workload on aircrew performance and to develop methods for insuring that the workload demands are well within the bounds of human performance capacity.

Initial efforts require the development of methods of measuring and predicting operator workload. No adequate method has been developed to date, although several approaches to the problem have been explored. The first step taken in this report is to summarize and evaluate the alternative workload methods that are presently available. Each method has advantages and limitations that are delineated and discussed in terms of potential application in Army aviation.

The next step would be to develop one or more of the promising methods of measurement. This may be accomplished by modifying an existing method or combination of methods or by developing a completely new approach.

Beginning in FY77, the US Army Air Mobility Research and Development Laboratory (now the US Army Research and Technology Laboratory), Moffett Field, California, initiated a project to develop computer based mathematical modeling of aircrew tasks and procedures. The objective is to generate a new preliminary system design engineering capability for automated task analysis, time line analysis, and other function-operational sequence studies for proposed helicopter cockpits.

It might be beneficial at this point to review what the Army's desires are in the area of automated/computerized workload analysis. The tactical doctrine of nap-of-the-earth (NOE) flight imposes greater demands on the aircrew than ever before. At NOE altitudes, the pilot spends over 85 percent of his vision time out-of-the-window, maintains almost continuous communication with the copilot and/or external sources and is involved in a non-stop effort of manipulating the flight controls to maintain the proper airspeed, altitude, and heading as dictated by the terrain. The copilot is communicating, monitoring engine instruments and the caution/warning panel and also serves as a navigator. Upon reaching some observation point, the copilot puts aside the navigation function and then performs a reconnaissance or target acquisition/designation function. It can be seen that both crewmembers are extremely busy during an NOE flight and the problem is compounded if the flight is at night.

Increased automation and sophistication has been introduced into current aircraft cockpits. The goal of this automation has been to reduce the man-in-the-loop requirements or to extend the capabilities of the crewmembers. The automation designed to reduce the man-in-the-loop will reduce workload; however, equipment added to expand the navigational, target acquisition, or fire control capabilities often greatly increases the workload.

With the increased sophistication in the cockpit and the critical impositions of NOE flight, it becomes clear that a predictive type of workload assessment would be most desirable.

In an effort to identify suitable alternatives for a starting point, the US Army Human Engineering Laboratory (HEL) has been tasked by the US Army Research and Technology Laboratory to perform a background literature search and survey. Based on this survey of computerized/automated systems for task/workload analysis, HEL may be able to recommend that (a) the Army use one of the existing systems, (b) modify an existing system, or (c) upon rejection of the existing systems, develop a new workload analysis system.

APPROACH

Two literature searches were conducted through the Defense Documentation Center and one through the National Technical Information Service. Additional abstracts were obtained from proceedings of the Human Factors Society, AGARD reports and various symposium proceedings. The responsible agencies were contacted to check the current status and determine if there was additional documentation available which did not appear during the literature searches. A greater in-depth investigation was carried out for the more promising approaches. Personal contacts were made and site visits were initiated to get a closer look at the system in operation, gain a better understanding of the system operation, and determine the systems applications and limitations. Based on the promise of each approach to fulfilling the Army's needs, tradeoffs were determined and recommendations made.

DISCUSSION

Operator workload and performance is one of those topics for which discussions are quite lengthy and quite numerous. One conclusion from all of these discussions would be that there is neither a single definition of workload, nor a single method for measuring it. At a crewstation design conference held in Los Angeles in September 1972, some of the following definitions of workload were put forth by various attendees.

1. Workload is the amount of effort expended in the performance of a task or tasks within certain established tolerances.

2. Workload should be defined in terms of what is required to handle emergency situations. Since crewstation design usually considers only the routine condition, the maximum workload must be such that the pilot has the reserve capacity to handle any imaginable emergency.

3. One of the more common definitions of workload is the ratio of time required to time available. With an unlimited amount of time, physical or mental capability to accomplish the task is rarely a problem. However, with time constraints the question is, "Can the pilot do everything necessary with the time available?" This time-motion type of analysis is also useful in determining the effects of specific equipment changes or modifications on pilot effectiveness in performing the mission.

4. With increasing sophistication in the cockpit, the motor tasks will diminish and the thinking component will be increasingly important. Therefore, the definition of workload must take into account the internal state of the man.

5. Pilot opinions and comments can relate that the workload for a particular mission segment or phase is acceptable. Quantifying workload is sometimes a problem. By measuring pilot activities, and maybe some physiological parameters, it may be possible over an extended period of time to obtain a statistical description of the task. Therefore, workload will be defined by the statistical description.

6. Workload is the amount of work expenditure required for the man to achieve acceptable performance.

7. Workload should be defined in terms of the percentage of the operator's capacity, using a given strategy and assuming a given level of skill, for accomplishing a particular ensemble of tasks.

As can be seen, there are a variety of definitions and concepts of workload among crew station design personnel. Almost as numerous as the number of concepts are the methods which are used to measure workload. One method of workload measurement is the subjective evaluation of the operators. This could be accomplished by interviews or questionnaires. This method is open to bias from both the operator and the evaluator. Operator bias could come from past experiences, opinions of co-workers, personal likes or dislikes, and the desire to give favorable responses to a question. Evaluator bias could be introduced through the wording of the question and the way questions are sequenced in order to draw some conclusion.

A popular technique for workload measurement is that of the secondary task. The secondary task technique measures the reserve information processing capacity of the operator. The more time the subject has to devote to a secondary task, the less demanding the primary task. In this manner, the secondary task performance is correlated to the primary task difficulty. Also, the secondary task must be sensitive enough to determine the primary task difficulty.

The information processing technique determines how difficult a task is to accomplish and how well it is performed. The operator information processing workload is a measure of load imposed by task requirements on the operator's capability to process information quickly and accurately. The information processing workload imposed on the operator is dependent on the characteristics of the system, operational states, nature of assigned functions, level of skill required, and control/display compatibility and intelligibility. Once the information capacity is exceeded, performance degrades.

Physiological measures is another technique for quantifying workload. Changes in various physiological parameters; such as heart rate, EKG, EEG, etc., are used to determine how hard an operator works to process information and to achieve a level of performance. A combination of performance and physiology could yield an index of information processing workload.

Another technique to measure workload is an attention and effort model of operator workload. Operator behavior is greatly influenced by mechanisms that control the selection of stimuli. That is, operators selectively attend to some stimuli in preference to others as well as investing more attention to some sources of information than others. Voluntary attention indicates that the operator attends to certain stimuli because of the reliance upon that stimuli for performing a task. Effort can be thought of as the selective attention to a task dependent stimuli. The amount of effort expended by an operator is dependent upon relevant task stimuli which are

necessary to complete the task. Involuntary attention can also be included in this concept of effort and is related to the level of arousal dictated by the properties of the stimuli. A familiar stimuli requires less effort than a new stimuli.

All of the above techniques for workload measurement and quantification require test apparatus such as an aircraft or simulator, which is capable of providing feedback to the operator. It is rather late in the developmental cycle when aircraft or simulators are available for use. Design changes at this stage, if possible at all, are time-consuming and expensive. What is sorely needed is a method for obtaining workload measures early in the development process.

Computer-aided simulation provides this capability. The object of any computer simulation is to represent a man-machine system faster, cheaper, and at greater convenience than the actual system itself. A computer program can manipulate the tasks to be performed, task priorities, resources, time intervals, level of performance, and a multitude of other variables and also perform mathematical calculations. Computer simulation has proven a valuable asset in "predicting" areas of concern with regard to overloading crewmembers. The benefit of the computer program is that it can follow the development process. As design changes are made, or proposed, a similar change can be made in the program to assess the impact of the change.

The following is a summary of the existing computerized programs for assessing aircrew workload which were examined for their applicability to meeting the Army's requirements. Each computer program was examined in terms of input requirements, processing, outputs available, limitations, and any other pertinent data. While there may be other programs available, these are the ones which this author has been able to identify. A more complete description of each computer program can be found in the supplement to this report. (The supplement is only available from the US Army Human Engineering Laboratory.)

The computer programs examined are as follows:

1. Avionics Evaluation Program (AEP) (Air Force Avionics Laboratory). The existing AEP is a library of five individually-executable detailed avionic performance assessment models. The library currently includes (a) a detailed air-to-ground mission analysis program, (b) a free-fall weapon delivery analysis program, (c) a multi-sensor target acquisition analysis program, (d) a multiple aircraft air-to-air mission analysis program, and (e) an air-to-air dogfight simulation.

2. Computer-Aided Function Allocation and Evaluation System (CAFES) (Naval Air Development Center). CAFES computer aids consist of a set of submodels working in conjunction with a data/information management system. As required, each submodel may be used individually or in conjunction with any of the others at any point in the development cycle. The CAFES submodels include the Data Management System, Function Allocation Model, Computer-Aided Crew Station Design Model, Crew Station Geometry Evaluation Model, Human Operator Simulation Model, and Workload Assessment Model. The purpose of the Workload Assessment Model (WAM) is to assist the human factors engineer in deriving workload estimates for operators in new or existing systems. The workload estimates generated by WAM are a function of the time required to perform a series of tasks. It is not concerned with other measures of workload such as the amount of hand or eye travel, amount of effort expended, or fatigue effects. The quality of the workload estimates obtained from WAM are directly related to the quality of the input data.

3. Douglas Crew Workload Analysis (Douglas Aircraft Company). For several years, the Douglas Aircraft Company has been conducting a program directed toward developing the ability to objectively measure flight crew workload with sufficient sensitivity to differentiate between

alternate crew station configurations. The major objective of the development of this system is to obtain quantitative flight crew workload which is equipment related.

4. Advanced Attack Helicopter (AAH) Crew Workload Analysis (Hughes Helicopters). The purpose of the task load analysis is to determine workload level, the proper order in priority of crew duties, and the probability and times of crew saturation. It further provides information for task relocation and/or control/display reconfiguration so that the crew will be able to perform all duties and functions during the several mission profiles of the AAH.

5. MX Crew Ratio Simulation Model (USAF School of Aviation Medicine). The basic function is to match resources against requirements which must be flown; that is, a specified utilization rate. This matching is subject to certain physical constraints and to operating policies defined to the program by the user. The goals of the model are to measure system performance and to determine whether available resources are adequate for assigned workload. More specifically, the model seeks to determine whether a specified crew ratio is adequate to sustain a given utilization rate without imposing untenable workloads on crew members.

6. Systems Analysis of Integrated Network of Tasks (SAINT) (Aerospace Medical Research Laboratory). The SAINT philosophy is to separate modeling from analysis. A graphical approach to modeling is taken in which the system to be analyzed is represented by a network model. A SAINT network model describes a system in network terms using the SAINT symbol set. The fundamental elements of SAINT networks are tasks, resources required to perform the tasks, relationships among tasks, and system status variables referred to as state variables. System performance is related to which tasks are performed, the manner in which they are realized, and the extent to which certain states of the system are achieved or maintained. The generalized SAINT symbol set provides a vehicle for modeling resources performing tasks to accomplish system objectives.

7. Siegel and Wolf. Within the advent of complex systems in which a human is expected to operate, it has become increasingly more likely to find that during operational usage the operator is overburdened or underburdened during the task. An after-the-fact remedy, if feasible at all, can be time consuming and expensive. This psychologically oriented model has been developed and refined in order to simulate the characteristics of the human operator in a man-machine system. Its goal is to allow a determination of where a man-machine system may overload or underload the operators while the system is in the early design stage.

CONCLUSIONS

One point that should be reiterated here is that this report does not purport to have examined all existing computerized workload analysis programs, but only those which the author has been able to identify through literature searches, report bibliographies and personal contacts. It is quite possible, even probable, that other programs exist. Failure to identify these other programs was not intentional and should not be construed as a dissatisfaction with the program or model. On the other hand, the fact that a particular program or model has been mentioned does not imply an endorsement in assisting the Army to reach its desired goals.

In summary, it is desired to have a computer program with which predictions can be made, with a high degree of confidence, to identify potential areas or sources of high workload situations so the appropriate corrective action(s) can be taken.

While examining the computer programs, three questions had to be considered. They were:

1. Do any of the existing programs have all of the features (computations, output, etc.) that are deemed to be desirable?

2. Can the desired program be obtained by combining the features of several of the programs?

3. If the answers to questions 1 and 2 are "NO," is it necessary to develop the desired program from scratch?

Each of the questions will be addressed separately.

Do any of the existing programs have all the features that are deemed to be desirable? All of the computer programs are based on a timeline analysis; that is, the time required to perform various operations versus the time available. Certain data are required by the computer as input. The computer will perform a series of operations on this data, as directed by the programmer, in order to make the comparison of time required to time available and then present the results in a form that is also dictated by the programmer. Therefore, the features included in a computer program are determined by the programmer by assessing his desired end result and designing a software package to meet the need.

There is not one program which has all of the desired features. It would seem desirable for the Army to have available a single computer program which can incorporate the numerous features and options possible. Then, when running the program to assess a specific situation, the programmer can delete these features or options that are not required from that particular run. In the evaluation, the answer to question 1 is NO.

Can the desired program be obtained by combining the features of several of the programs? Before this question can be addressed, it is beneficial to examine the sources and availability of the computer programs. The sources and availability can be divided into two groups--military and private industry. The computer programs that were developed by private industry were done at great expense (in terms of time, money, and resources) and sometimes deal with information which is proprietary in nature. For these reasons, private industry is generally reluctant to share their programs without the proper compensations.

The military organizations, the Naval Air Development Center and the Air Force Aerospace Medical Research Laboratory and Air Force Avionics Laboratory, have been most willing to share their information. As all of the features of the private industry programs are included in at least one of the military programs, it does not seem useful to continue discussing trade-offs with programs developed by private industry. From this point on, discussions will center around the SAINT and the CAFES systems. The Avionics Evaluation Program deals with target acquisition and weapon delivery and does not really cover a mission workload analysis.

Some desirable features of the SAINT program are:

a. Many possible distributions can be used to specify a time rather than just a constant value.

b. Branching from one task to another can be accomplished based on probabilities.

c. Weighting factors can be applied to simulate degradation of performance due to stresses such as fatigue or night flight.

d. Time intervals for reporting workload can be of any length.

e. Repetitions of tasks can be accomplished in loops.

f. Task descriptions and actions can be as fine and minute as desirable.

g. Output can be in graphical as well as tabular form.

Some desirable features of the CAFES program are:

a. The operator is described by nine body channels and workload values are computed for each body channel.

b. The program will attempt to move tasks to a different time interval when overload conditions are reached.

c. The program will automatically indicate the tasks in progress when specified limits of workload are exceeded.

d. Summary reports can be obtained for utilization of a subsystem or a particular piece of equipment.

e. Output can be in graphical as well as tabular form.

In response to question 2, it seems that a combination of the SAINT and CAFES programs would allow the choice of almost any option. It should be mentioned that both programs seem adequately capable of providing a predictive workload assessment. A choice between the two cannot be made at this time.

Is it necessary to develop the desired program from scratch? This would not be a wise decision. There are several programs (primarily the SAINT or CAFES) which could serve as a starting point and by using this as a building block would save a great deal of effort. It would be much more effective to start with one of the programs and then modify it as desired.

RECOMMENDATIONS

For immediate use as a computer program to predict high workload conditions, the SAINT program or the Workload Assessment Model of the CAFES program are recommended. Both of these programs are readily accessible to the Army and provide many of the desired capabilities.

At this time it is difficult to choose between them, but in order to provide the Army with its desired flexibility this determination should be made. It is recommended that a sample problem be submitted to each program. The sample problem will define the mission segment, tasks to be performed, and the desired results. Based on the submission of the sample problem, it can be determined which program can meet the desired output with the minimum programming exercises.

Another recommendation would be to combine the features of the SAINT and CAFES into a single program.